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Organic Mine Countermeasures (OMCM)
Future Naval Capabilities (FNC)

Combined Joint Task Force Exercise (CJTFEX) 04-2 ARIES-TERN Network Connectivity Experiment Quicklook Report

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Combined Joint Task Force Exercise (CJTFEX) 04-2
ARIES-TERN Network Connectivity Experiment Quicklook Report

1.0 Introduction

The Office of Naval Research (ONR) Organic Mine Countermeasure (OMCM) Future Naval capabilities (FNC) Program Office objective to expedite the implementation of new war fighting concepts and complementary mine countermeasures (MCM) technologies, is enhanced through Fleet demonstrations. Technology demonstrations garner and maintain Fleet advocacy for OMCM FNC initiatives and assist in the validation and improvement of the military utility of prototype systems. The Program Office plans to demonstrate autonomous underwater vehicle (AUV) technologies during two FY 04 major exercises, the NATO exercise BLUE GAME 04 and Combined Joint Task Fleet Exercise (CJTFEX) 04-2. This report documents ONR observations during experiments conducted by the Naval Postgraduate School (NPS) during CJTFEX 04-2.

The primary objective of these observations is to assess the military utility and application of the NPS Aries/Tern system in a real-world exercise environment. An additional objective will be to collect information to enable an assessment of individual system performance and the performance of system components to mark development progress and capability using standard measures of performance and effectiveness. Underlying this objective is the Chief of Naval Operations' (CNO) mandate to expedite the implementation of new warfighting concepts and technologies. ONR is addressing this by fielding complementary MCM technologies with emphasis on near shore operations and the use of unmanned vehicles.

2.0 System Description

The major components of the NPS experiment are described in this section.

2.1 Acoustic Radio Interactive Explorer Server (ARIES) Autonomous Underwater Vehicle (AUV).

The ARIES is a shallow water communications server vehicle measuring approximately 3 meters long, 0.4 meters wide, 0.25 meters high, and weighing 225 kilograms. A flooding fiberglass nose is used to house external sensors, power switches, and status indicators. The hull is constructed of 0.25 inches thick 6061 aluminum that contains all the electronics, computers, and batteries. Six 12-volt rechargeable lead acid batteries power the ARIES. The endurance is approximately 3 hours at a top speed of 3.5 knots, or 20 hours for a hotel load only. ARIES can operate safely at a depth of 30 meters. Figure 2-1 shows the ARIES as configured for CJTFEX 04-2 and Figure 2-2 shows the major hardware components of the ARIES.

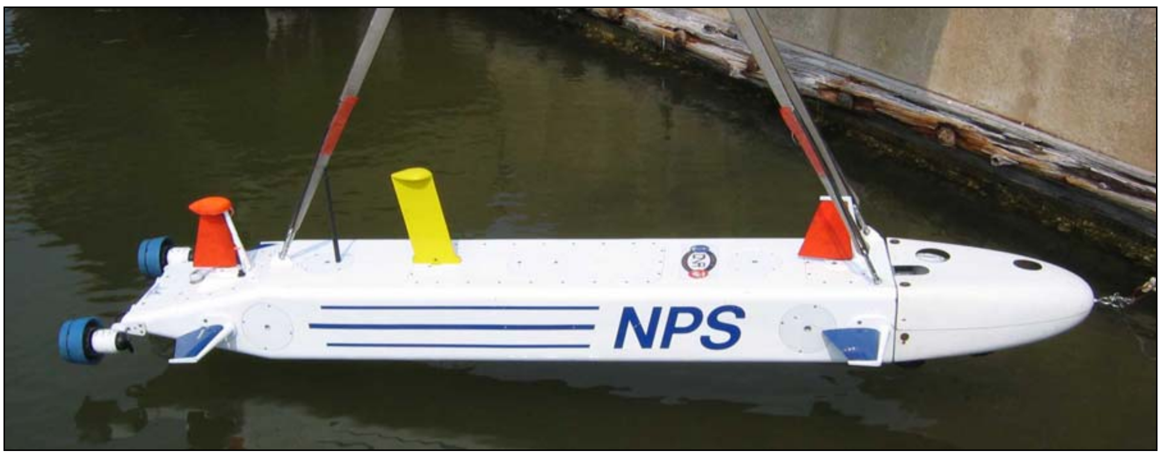

Figure 2-1. ARIES AUV

Twin 0.5 Hp electric drive thrusters located at the stern provide propulsion. Bsow and stern rudders and a set of bow and stern planes control heading and depth, respectively. The navigation sensor suite consists of a 1200 kHz RD Instruments Navigator Doppler Velocity Log (DVL) that also contains a TCM2 magnetic compass. This navigation suite measures vehicle altitude, ground speed, and magnetic heading. Angular rates and accelerations are measured using a Systron Donner 3-axis Motion Pak IMU. While surfaced, differential GPS (Ashtech G12-Sensor) is available to correct any navigational errors accumulated during the submerged phases of a mission. In addition, a Honeywell HMR3000 magnetic-restrictive compass, corrected by a deviation table, is used as the primary heading reference standard.

A fixed wide-angle video camera (Deep Sea Power and Light – SS100) is located in the nose and connected to a Digital Video Recorder (DVR). The computer is interfaced to the recorder and controls the on/off and start/stop functions. The video image has the date, time, position, depth and altitude superimposed onto it.

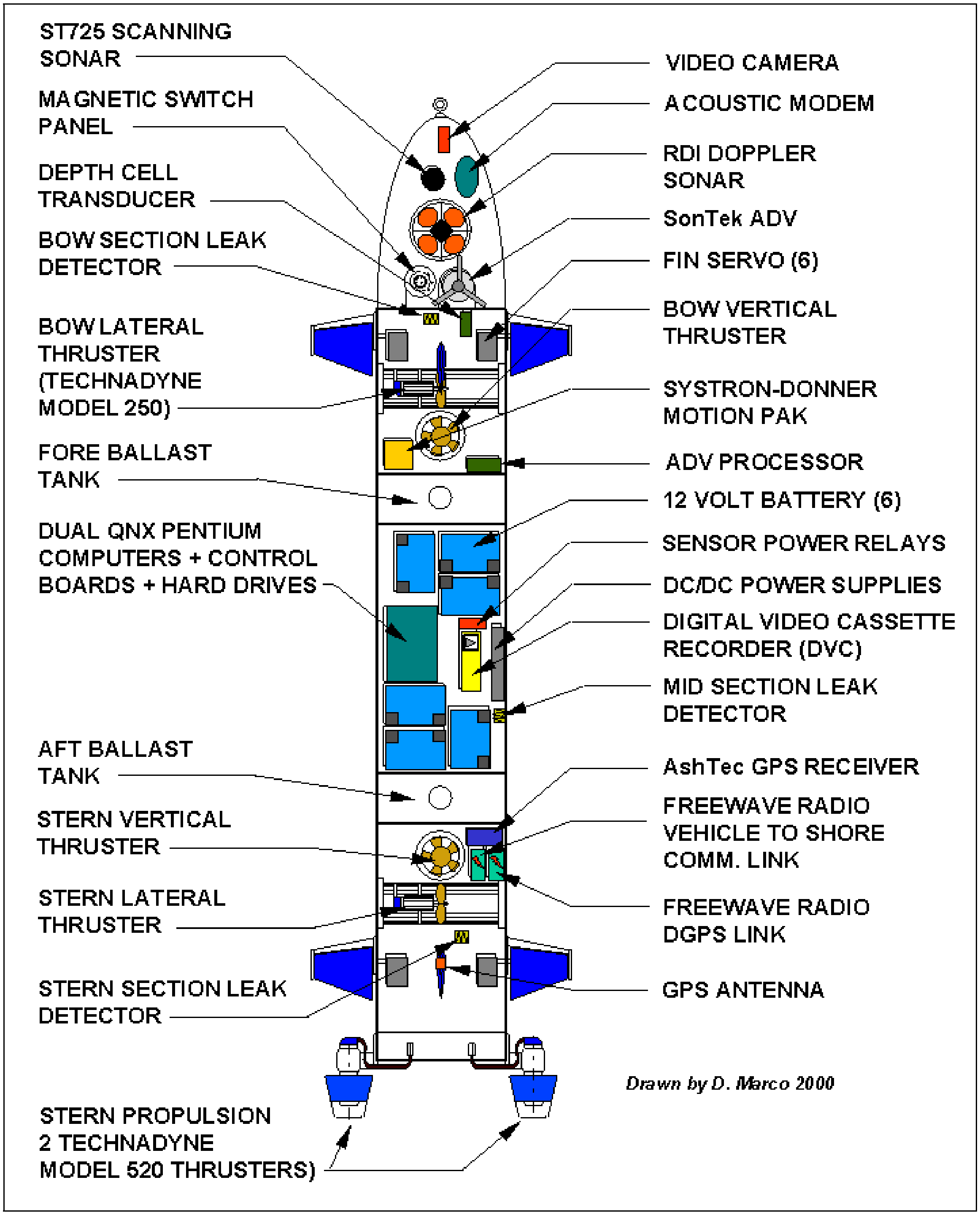

Figure 2-2. ARIES Major Hardware Components

A scanning sonar (Tritech ST725) or a profiling sonar (ST1000) is used for obstacle avoidance and target acquisition/reacquisition. The sonar can scan continuously through 360 degrees of rotation or be swept through a defined angular sector.

Freewave Radio Modems are used for moderate bandwidth (2000-3000 bytes/sec over 4 to 6 nautical miles with repeaters) command and control (C2) between command center and the vehicle when surfaced. Kermit file transfer protocol is used in the vehicle computer with Zmodem through Procomm protocol on the base station side. ARIES also has an FAU acoustic modem installed onboard. For CJTFEX 04-2, ARIES was configured with an 802.11b bridge, a 1W amplifier and an antenna to provide data transfer between ARIES and other network nodes.

2.2 Tactically Expendable Remote Navigator (TERN) Unmanned Aerial Vehicle (UAV)

The BAI Aerosystems TERN is a compact, tactical UAV capable of performing a variety of remote sensing, precision dispensing and other aerial robotic missions. TERN is constructed of composite materials and features a high wing design and increased ground clearance, which allows operation from runways and semi-improved surfaces. A 100cc two-stroke, gasoline/oil engine powers the TERN.

TERN employs a global positioning system (GPS) autopilot that controls vehicle heading, altitude, airspeed, and GPS waypoint navigation. A 10-watt video/telemetry microwave datalink transmits real-time imagery and vehicle telemetry back from the aircraft at ranges up to 50km. For CJTFEX 04-2, TERN was equipped with an 802.11b bridge, a 2W amplifier and an antenna, mounted in the nose. Figures 2-3 and 2-4 provide illustrations of TERN operations. Table 2-1 provides the TERN's specifications.

Figure 2-3. TERN

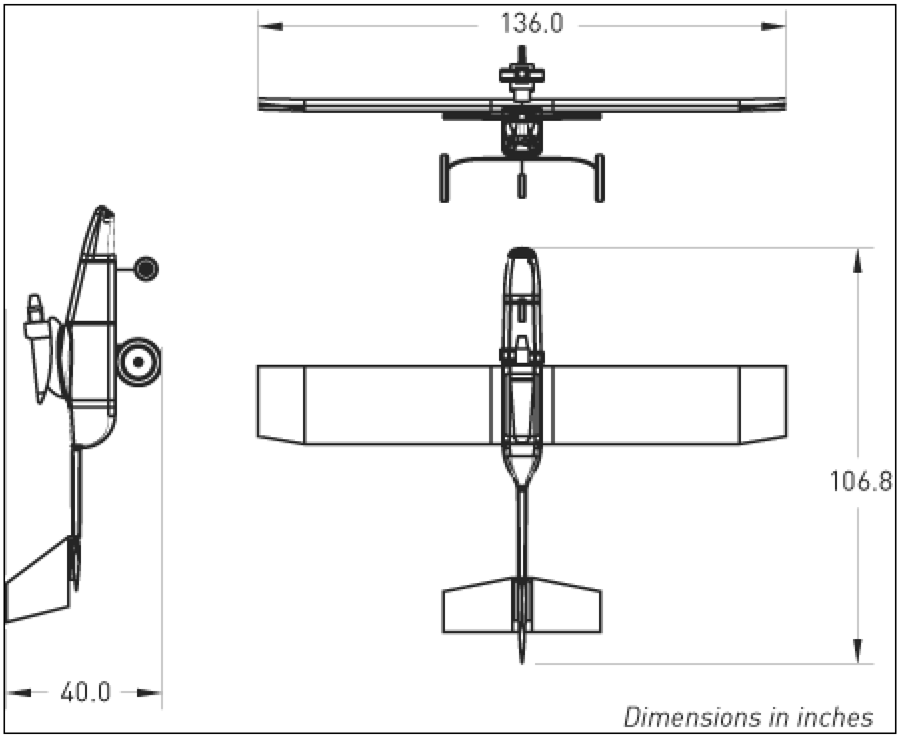

Figure 2-4. TERN Dimensions

Table 2-1. TERN Specifications

TERN Specifications	
Stall Speed	45 mph
Max Speed	78 mph
Cruise Speed	52 mph
Operational range (still air)	200 miles
Operational Endurance	4 hours
Ceiling	5000 - 6000 ft.
MGTOW	130 lbs.
Empty Weight	95 lbs.
Maximum Fuel	28 lbs.

For CJTFEX 04-2, Navy Composite Squadron SIX (VC-6) used the TERN Ground Control Station (GCS) shown in Figure 2.5. The GCS features a microwave receiver, amplified uplink transmitter and a rugged laptop computer with flight control software. The TERN's typical payload is a slewable infrared (IR) or electro-optical (EO) sensor. For CJTFEX 04-2, the payload is the NPS bridge.

The TERN crashed upon its initial take-off during CJTFEX 04-2. Repairs were not possible during the exercise and the UAV did not play its intended role.

Figure 2-5. TERN GCS

2.3 Balloon

As a backup to the TERN, NPS brought a 13-ft. diameter balloon capable of 60-lbs of lift. Due to the TERN's crash, the balloon was the key network relay node for the entire exercise. The balloon's payload consisted of an 802.11b Cisco bridge with a 5W amplifier and a 6dB gain omni-directional antenna. It also included a 12-channel GPS Receiver and the 900MHz Freewave transmitter for the GPS broadcast. The payload was powered by two 5390 Li-MnO2 Batteries. The balloon and its payload are shown in Figure 2-6.

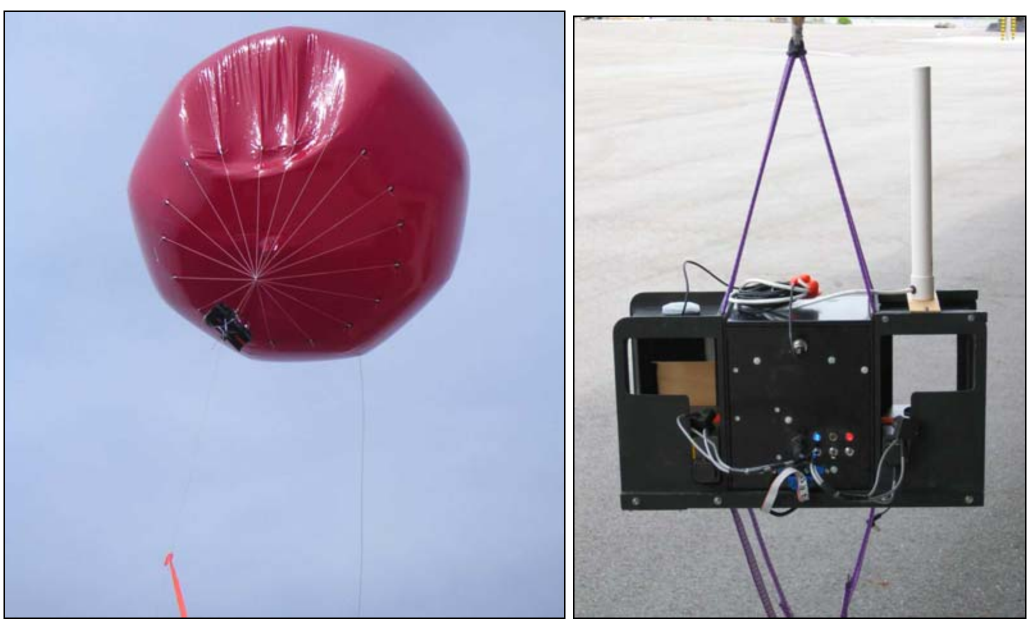

Figure 2-6. Balloon and Balloon Payload

2.4 K2 System

Sierra Nevada Corporation's (SNC) K2 was used as the command node, or mini Network Operations Center (NOC) for this exercise. The K2 consists of the following components:

- Cisco AERONET 350 802.11b wireless bridge
- 14dBi Antenna on a 2-axis gimbal
- 2W 802.11b Amplifier
- Integrated GPS receiver
- PC-104 Computer

In addition, the mini-NOC node had a 900MHz Freewave radio to receive GPS data from the TERN and balloon. The K2 is shown in Figure 2-7. The K2 was connected to a Panasonic Toughbook laptop that was used to network with the computer onboard ARIES and the laptop aboard the Whaler during the various network file transfer tests. The mini-NOC laptop also hosted the SolarWinds software applications used for network testing and management.

Figure 2-7. Mini-NOC with K2

2.5 Whaler Bridge

The host platform for the ARIES was a twin-outboard Boston Whaler powerboat shown in Figure 2-8. The USMC Marine Safety and Security Patrol for MCB Camp LeJeune provided the Whaler and crew. For CJTFEX 04-2, the Whaler carried an 802.11b Cisco bridge with a 2W amplifier and an omni-directional antenna. It was also equipped with a 900MHz transceiver for communicating with the ARIES. For file transfer tests between the Whaler and the mini-NOC, a Dell Laptop was connected to the Whaler bridge.

Figure 2-8. Guard Boat Four (Whaler)

2.5 Network

Table 2-2 provides a list of the CJTFEX 04-2 network nodes. Figure 2-9 illustrates the CJTFEX 04-2 network, including the 2.4GHz 802.11b data links and the 900MHz Freewave command and control link.

Table 2-2. ARIES File Transfer Test Nodes

Node Name	IP Address	Description
Blue Command Post	192.168.1.71	not used
Blue K2	192.168.1.72	802.11 bridge receiving data from K2 directional antenna
Blue TERN	192.168.1.74	not used
Blue Balloon	192.168.1.75	802.11 bridge in communications relay b
Blue ARIES (bridge)	192.168.1.76	802.11 bridge in ARIES vehicle
Blue Whaler	192.168.1.77	802.11 bridge onboard Whaler (ARIES host platform)
Blue PC104	192.168.1.78	ARIES Computer
Whaler Laptop	192.168.1.80	Laptop computer onboard Whaler
Blue mini-NOC	192.168.1.82	Laptop acting as mini-NOC receiving files from ARIES

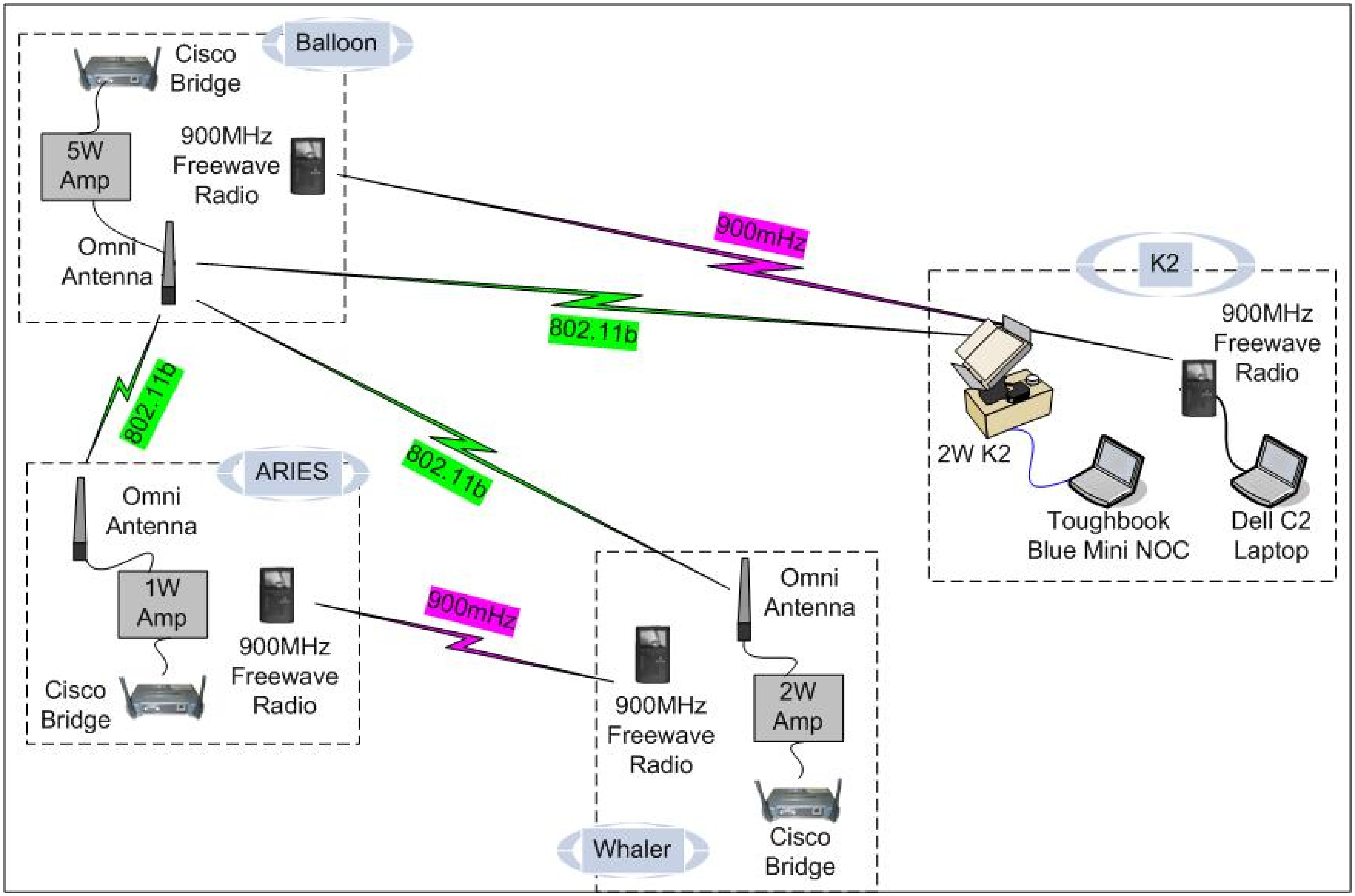

Figure 2-9. CJTFEX Network Architecture

3.0 Test Description and Results

NPS's objectives for the ARIES/TERN System during CJTFEX 04-2 were:

- Demonstrate high bandwidth links for sonar and/or video file transfer between the ARIES AUV, the TERN UAV and the K2 Tactical Operations Center
- Demonstrate 802.11b network links for AUV and UAV assets over distances greater than 4km at 200-300 kbps.

NPS stated the operational requirements for developing this technology as:

- Robust communications for command and control and data transfer are required for teams of vehicles deployed in an area to scout and report on oceanographic conditions and the mine threat
- Collected data is voluminous and requires a high bandwidth data link
- Data needs to be collected and distributed quickly for rapid operational planning
- Not all vehicles may return from missions – the data still needs to be collected.

The solution offered by this technology provides unmanned systems with high bandwidth communications (currently 802.11b) using a UAV as a bridge between an AUV and a command cell located some distance from the AUV. The technology also automates the path of the UAV to optimize the link between the groups of vehicles.

The remainder of this section will provide a description of the tests and results.

3.1 Pre-Exercise Events. On Thursday June 5, the ARIES was successfully ballasted and the NPS Team completed a functional testing of subsystems. Assembly of the TERN was completed and readied for a test flight. On Friday June 4, the NPS Team conducted a tow test of ARIES using Guard Boat Four. Maximum tow speed was six knots, though higher tow speeds were eventually used (up to 7 knots). On Saturday June 5, the TERN crashed during its first test flight (see Figure 3-1). Due to the TERN crash, the balloon acted as a surrogate UAV during the entire exercise.

Figure 3-1. TERN Crash

3.2 Exercise Results. Tests were conducted on 7 and 9 June to determine the maximum range of the 802.11b link. Tests were conducted on 6 and 8 June to determine the file transfer rates of various network configurations. These tests are described below.

3.2.1 Maximum Range Tests. On 7 and 9 June, tests were conducted between the network nodes to determine the maximum range of the 802.11b data link.

Maximum Range Test One. Moving the location of the mini-NOC and K2 to the south along the North Carolina shoreline varied the range of the network. On 7 June, a maximum two-node link range of 18.9km was achieved between the K2 at North Topsail Beach and the balloon flown from near the South Tower at Onslow Beach. The tests were conducted between 1315 and 1400 Local and the weather was extremely humid and hazy. The K2's position was 34°27.652'N, 077°29.082'W and the balloon's position was 34°32.792'N, 077°18.375'W. Collected data and screenshots are provided in Appendix A. Figure 3-2 illustrates the test network and Figure 3-3 shows the test geography.

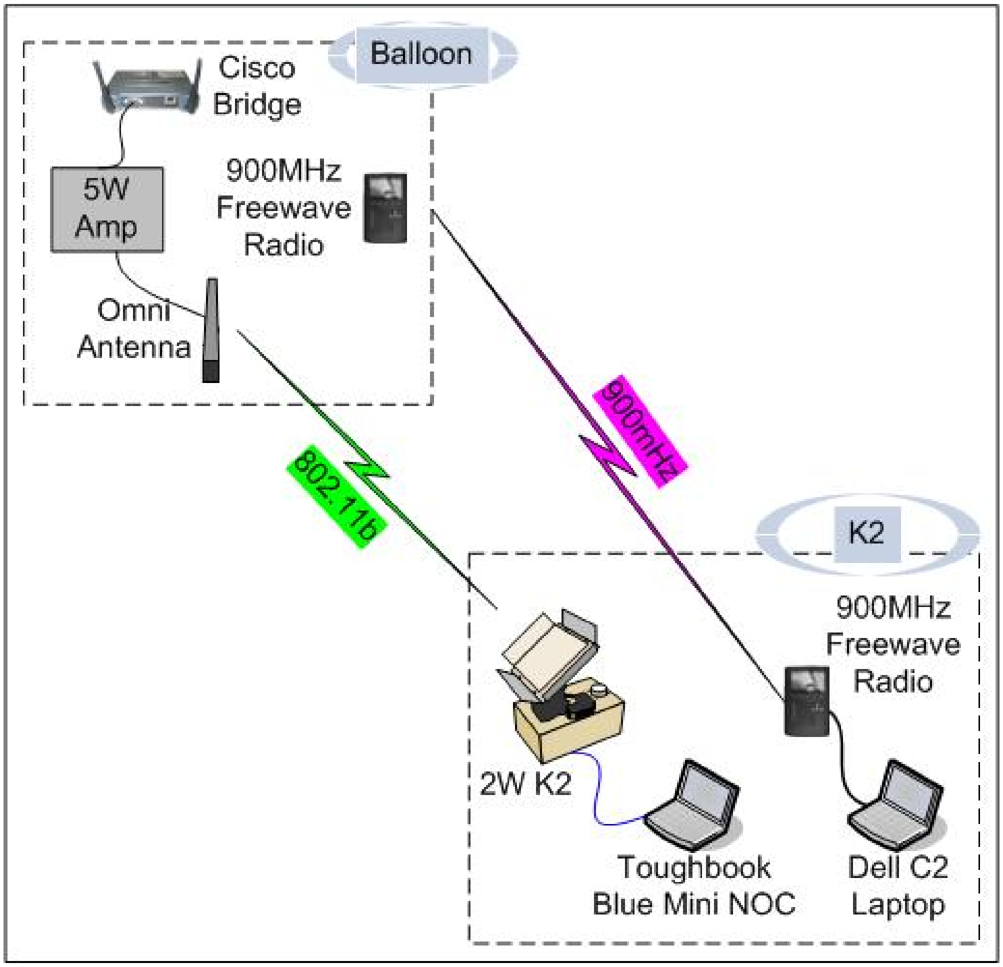

Figure 3-2. Maximum Range Test 1 and 2 Network

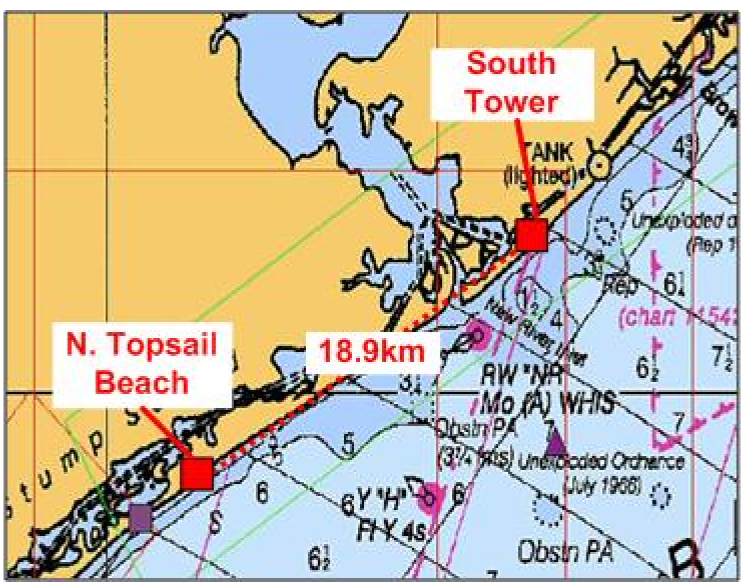

Figure 3-3. Maximum Range Test 1 Geography

Maximum Range Test Two. On 9 June, the Maximum Range Test of 7 June was repeated, as shown in Figure 3-2. The weather was less humid and hazy. First, a maximum link range was obtained with the mini-NOC and K2 at North Scotch Bonnet Beach, approximately 19.9km from the balloon at South Tower, as shown in Figure 3-4. During these tests it was observed that the manually set position of the K2 was critical for link quality. Small changes in both bearing and azimuth produced significant changes in link quality. Collected data and screenshots are provided in Appendix B.

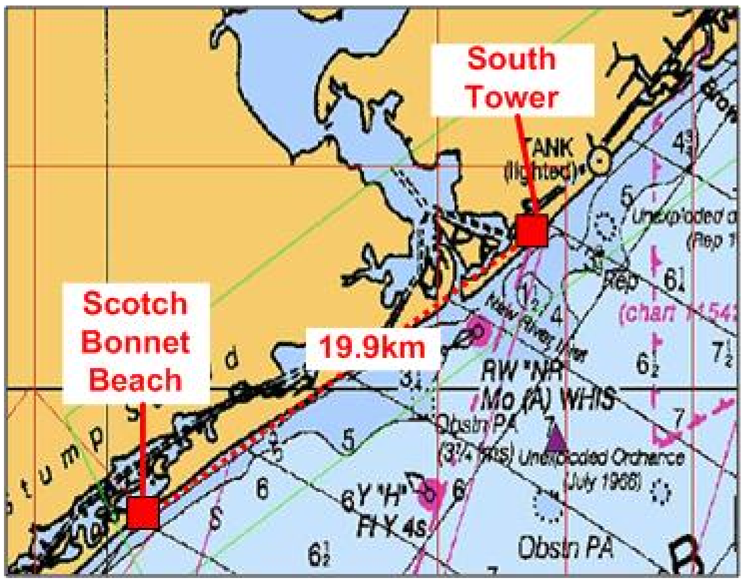

Figure 3-4. Maximum Range Test 2 Geography

Maximum Range Test Three. After the maximum K2 range was established, the next step was to discover the maximum range of a three-node 802.11b network between the mini-NOC K2 and the Whaler, with the balloon acting as a network communications relay (see Figure 3-5). The K2 was moved in to the North Topsail Beach location (34°27.650'N, 077°29.083'W) at a range of 18.9km from the balloon at South Tower. This range was the maximum distance where a stable link could be established on this day between the K2 and the balloon. The Whaler then took position at 2.5km seaward from the balloon. A network link was successfully established and a set of three ARIES video files was transferred from the Whaler laptop to the mini-NOC laptop using Microsoft Windows file sharing (drag and drop between Windows folders). The file transfer time was measured and file transfer rate in kbps was calculated for each run. The test continued with the Whaler increasing its range to seaward from the balloon in approximate 1-km increments. The maximum 802.11b link range between the Whaler and balloon was 8.0km as shown in Figure 3-6.

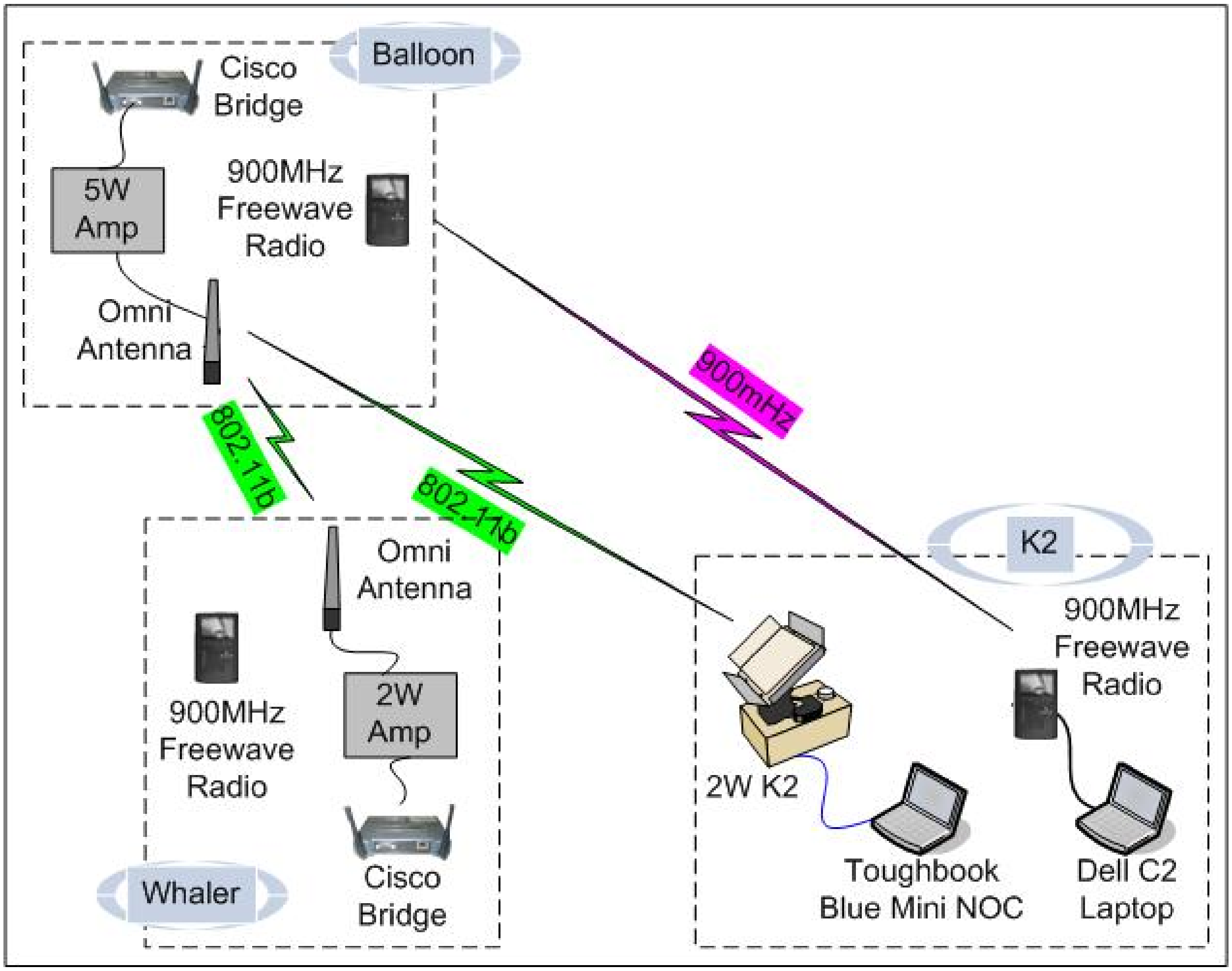

Figure 3-5. Maximum Range Test 3 Network

This test resulted in a maximum three-node link range of 26.9km from the mini-NOC K2 to the Whaler using the balloon as an airborne relay node. File transfer rates at this maximum range averaged 160kbps for the three runs. It is anticipated that the link range and file transfer rates were limited by the hazy and humid atmospheric conditions and also by the 1000-ft. maximum elevation of the balloon. Also, there was limited time to optimize the many various settings of the Cisco 802.11 bridges, so the settings may have been sub-optimized for this particular situation. Further testing is planned and ranges beyond what was obtained in this test should be possible, although the 26.9km range obtained during CJTFEX 04-2 greatly exceeded expectations. Collected data and screenshots are provided in Appendix C.

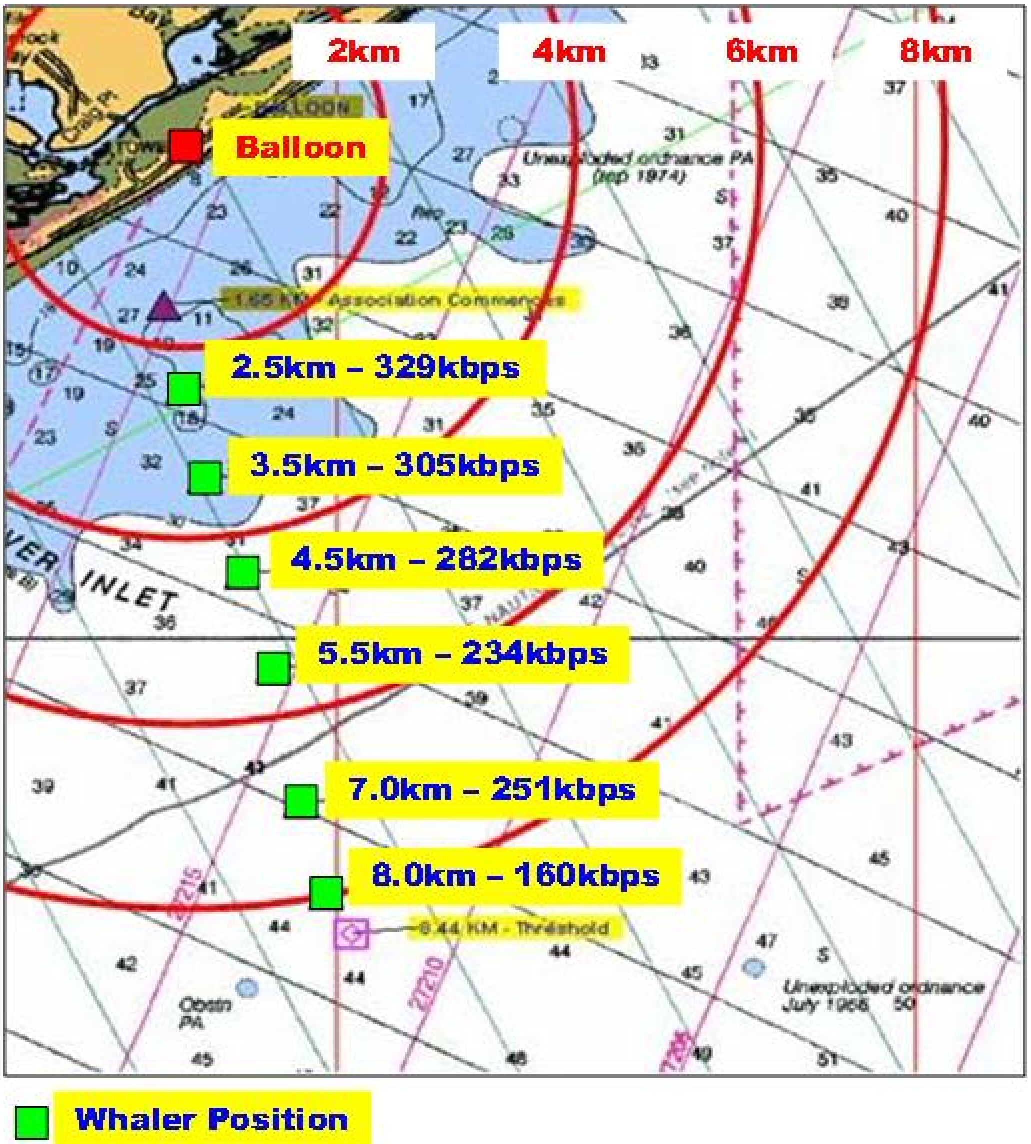

Figure 3-6. Maximum Range Test 3 Results

3.2.2 Data Transfer Tests. On 6 and 8 June, tests were conducted between the mini-NOC K2 and the ARIES to determine file transfer rates over the 802.11b data link.

Data Transfer Test One. The first set of tests on 6 June verified the ability of the network to transfer files at short ranges. The Whaler and ARIES were located in Mile Hammock Bay, just off Landing Zone (LZ) Bluebird. The mini-NOC with K2 was located at LZ Bluebird several hundred meters from the Whaler. Both nodes were approximately 2km from the balloon at South Tower, which was at approximately 187m altitude above mean sea level (MSL). The K2 operator then retrieved ARIES video files (2.796MB and 7.657MB in size) from the PC104 Data Acquisition Computer onboard ARIES using Windows file sharing. An average file transfer speed of 350kbps was achieved. Collected data and screenshots are provided in Appendix D. The network was as depicted in Figure 2-9.

<u>Data Transfer Test Two</u>. The second set of tests on 6 June extended the range of the mini-NOC K2 from the balloon out to the parking lot outside the LWTC, approximately 15.5km from the balloon. The balloon altitude was also raised to 342m. Collected data and screenshots are provided in Appendix E. The network was as depicted in Figure 2-9. The test geography is shown in Figure 3-7.

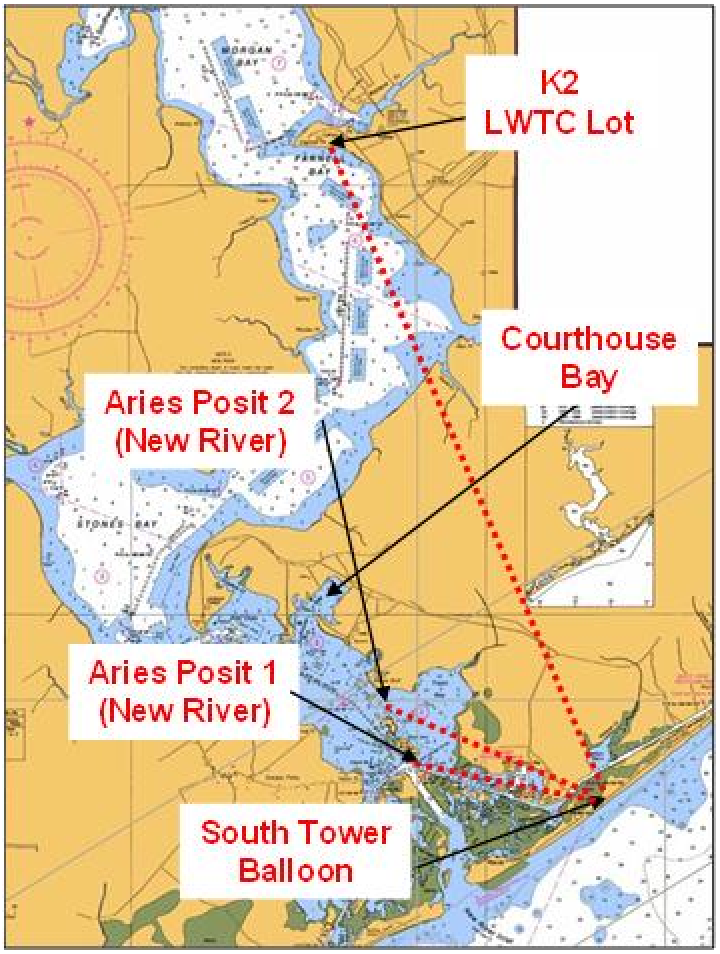

Figure 3-7. Data Transfer Test 2 and 3 Geography

During this test it was observed that when moving the K2 from LZ Bluebird to the LWTC increased the link range a 72.6% increase in average file transfer rate occurred (average of 604kbps vs. 350kbps). The NPS Team theorized this was probably due to some short-range effects that negatively affect link quality.

While the balloon was being lowered, the link degradation was observed (see Figure E-20). At 150m altitude, a solid link was still observed. At 100m altitude, a 3% packet loss was observed. By the time the balloon reached 77m, a rapid increase in packet loss was observed. At 65m the link was lost.

<u>Data Transfer Test Three</u>. The third set of data transfer tests were conducted on 8 June. Because of a fault in the ARIES, files could not be retrieved from the ARIES computer, so the

Whaler laptop was used as a surrogate. The architecture for this day is represented in Figure 3-5. The test consists of the mini-NOC K2 node at the LWTC parking lot, the balloon at South Tower and the Whaler in New River, as shown in Figure 3-7. It was observed that the Freewave link was lost when helicopters flew over the mini-NOC site, probably due to some RF transmissions that interfered with the 900MHZ Freewave link. The link would be restored after the helicopter passed.

Also during this test, a streaming video test was conducted. A 7.657MB video file was executed on the Whaler laptop from the mini-NOC laptop using Windows file sharing. The video file was played on the mini-NOC laptop over a period of 168 seconds, although the native file real-time length was much less. The video seemed to play continuously, although slower than expected.

3.3 Post-Exercise Events. Thursday June 10 was MIW Day. The day was spent on exercise debriefs at the Littoral Warfare Training Center (LWTC) and an exhibit of exercise systems at Courthouse Bay.

4.0 Summary

The NPS Aries/Tern mission was a qualified success. The mission demonstrated the ability to create a stable 802.11b network with three nodes with a total length of 27km. Data files were moved along the network at file transfer rates ranging at a maximum of 800 kbps down to 160 kbps at maximum node separation (max range).

As stated in Section 1.0, the primary objective of these ONR observations is to assess the military utility and application of participating OMCM FNC systems in a real-world exercise environment. It appears that 802.11b technology does represent one means of providing a high bandwidth (200 to 800kbps) link between autonomous and unmanned vehicles and other network nodes using standard Windows networking. The architecture is relatively simple to set up, uses COTS components, and is relatively secure. A significant drawback is that 802.11 could easily be jammed.

The secondary objective was to collect information to evaluate how these systems can be better integrated onboard the military host platforms. Because of the relatively small and lightweight components involved, this 802.11b data architecture could fairly easily be integrated into existing and future UAVs and AUVs. The biggest weight concern comes from the batteries. The length of mission operating time required dictates the size and weight of the batteries. The command part of the system should easily be integrated into a Modular Mission Package (MMP) design, though this was not investigated as part of this exercise.

The third and final objective was to collect information to enable an assessment of individual system performance to mark development progress and capability using standard measures of performance and effectiveness. The results from this exercise are contained in the Appendices to this report, in the primary data file (Aries-K2 Data.xls), and summarized in Section 3.0

Hardware problems, including the crash of the TERN AUV and the failure of the ARIES DVR, prevented the mission from demonstrating all of the functionality intended for the exercise. The TERN aircraft would have enabled a demonstration of greater network ranges due to its ability to fly higher than the balloon. The presence of the TERN also would have enabled the demonstration of the K2 unit's tracking mode, a significant feature. The absence of the ARIES digital video recorder (DVR) prevented only the demonstration of the capability of the system to obtain underwater video imagery and then transfer stored video to ARIES' PC104 computer. Pre-stored video files were transferred along the network instead.

Despite the hardware issues, the NPS experiment package successfully built upon prior experiments and demonstrated a reliable, secure and robust network connecting UUV platforms with the mini-NOC/TOC at the K2. This network allows COTS functionality and support and permits the operator to access real-time sensor data in remote locations. Like many COTS wireless applications, the use of the commonly available 802.11b spectrum is subject to jamming or unintentional interference and provides the greatest use in connecting sensors in remote locations. However, 802.11b technology is a viable and effective means of transferring large files and streaming data feeds and is well suited for unmanned and autonomous vehicles. Future testing, most immediately at the STAN 7 experiments set for 19-24 August 2004 at Camp Roberts, California, will provide an opportunity to demonstrate these capabilities and continue expanding the network capabilities. Future demonstrations would include additional network

nodes, multiple sensor output formats, greater network ranges and optimization of 802.11b link settings. It is also recommended that newer technologies such as 802.11g (54Mbps) and Orthogonal Frequency Division Multiplexing (OFDM) be researched.